



## SPECIFICATION

## NOVEL DIABODY -TYPE BISPECIFIC ANTIBODY

This nonprovisional application claims priority under 35 U.S.C. § 119(a) on Patent Application No(s). 2003-038643 filed in JAPAN on February 17, 2003, which is(are) herein incorporated by reference.

## FIELD OF THE INVENTION

The present invention is related to a novel diabody type bispecific antibody, which may be used in a cancer-specific immunotherapy, a single-chain polypeptide constituting the antibody or each region contained therein, a nucleic acid encoding the polypeptide, a method for the production of the antibody, use of them as a pharmaceutical preparation, etc.

## BACKGROUND OF THE INVENTION

Surgical resection, chemotherapy, radiotherapy and immunotherapy have been mainly used alone or together as a treating method of cancer (malignant tumor). Although the immunotherapy is still in a developmental stage, it has a lot of potentiality-potentialities and is therefore expected to make further progress in the near future.

The immunotherapy specific to the cancer means a treating method in which a cytotoxic activity is eaFFECTED only upon cancer cells. As a drug showing the cytotoxic activity is combined with an antibody to have directivity in this therapy, it is now called a "missile therapy." Studies have now been carried out to find an antigen that will be effectively used for the preparation of the antibody with a minimum of side effects by targeting as the antigen a substance that is abnormally expressed in the cancer cells or that will change according to malignant alternation or canceration of cells. Such antigen is called a cancer-associated antigen.

Among antibodies with multiple specificity, an antibody with bispecificity (Bispecific Antibody: BsAb) is now studied intensively. The bispecific antibody can

bind specifically to two different kinds of antigens so that it will be utilized as a therapeutic agent having a specific anti-cancer effect. A diabody is a minimum unit of the above bispecific antibody. It was developed by utilizing the property that the variable region in the heavy chain (VH) and the variable region in the light chain (VL) derived from the same parent antibody will form a hetero-dimer through non-covalent bond (Hollinger, et al., Proc. Natl. Acad. Sci. USA 90, 6444-6448, 1993).

A diabody-type bispecific antibody is characterized by having low immunogenicity and high infiltrating activity into tumor tissues due to its low molecular weight (ca. 60,000), and by being easily mass-produced at a low cost with use of microorganisms such as *E. coli*, and by being easily altered in function by means of genetic engineering.

It is therefore strongly desired to develop the diabody-type bispecific antibody that may resolve problems encountered in the conventional cancer therapies, especially the problems that it is impossible to completely remove cancer cells located at a site where the structure of tissues is complicated and that there is no way to remove the remaining cancer cells after a surgical operation.

Up to now, as an example of the diabody-type bispecific antibody, a fused protein has been developed. It has bispecificity derived from an antibody against a glycoprotein MUC1 often observed on adenocytes and an anti-CD3 antibody, and further contains a super antigen such as cellular enterotoxin in the same polypeptide as the variable region of the antibody (PCT Publication No. WO02/06486).

However, since the conventional diabody-type bispecific antibodies are a recombinant protein produced with use of microorganism, they tend to be inferior in effectiveness and stability after administration to the bispecific antibodies chemically synthesized. The conventional diabody-type bispecific antibodies also have some problems or disadvantages such as that they have to be produced in a high concentration in order to obtain the same effects as those by the bispecific antibodies chemically synthesized.

On the other hand, it was already reported that an antibody specific to HER-2/neu(c-erb-2), one of epidermal growth factor receptors (EGFR) that are a cell membrane-bound glycoprotein, could reduce the tumor by about 20 % in breast cancer patients.

The present inventors have studied to resolve the above problems so as to develop a novel diabody-type bispecific antibody that shows an excellent effect, and finally succeeded in preparing a diabody-type bispecific antibody showing a more remarkable effect than the conventional diabody-type bispecific antibodies and chemically synthesized bispecific antibodies even in a very low concentration and in the absence of the super antigen.

## SUMMARY OF THE INVENTION

A first aspect of the present invention relates to a diabody-type bispecific antibody, having a first specificity to a human epidermal growth factor (EGF) receptor and a second speceifity to a surface antigen expressed by a cell having phagocytosis or cytotoxic activity.

A second aspect of the present invention relates to either of the two kinds of a single-chain polypeptide constituting the above diabody-type bispecific antibody, or a polypeptide constituting each region contained in the single-chain polypeptide.

A third aspect of the present invention relates to a nucleic acid encoding the above single-chain polypeptide or each region contained therein.

A ~~forth~~ fourth aspect of the present invention relates to a replicable cloning vector or expression vector comprising the above nucleic acid.

A fifth aspect of the present invention relates to a host cell transformed with the above vector.

A sixth aspect of the present invention relates to a method for the production of the above single-chain polypeptide, comprising culturing the above host cell to express the nucleic acid in it, collecting and purifying the above single-chain polypeptide.

A seventh aspect of the present invention relates to a method for the production of the above diabody-type bispecific antibody, comprising assembling the

single-chain polypeptides to form the above diabody-type bispecific antibody, and separating and collecting the diabody-type antibody.

A eighth aspect of the present invention relates to a pharmaceutical preparation comprising an active ingredient selected from the group consisting of the above diabody-type bispecific antibody, the above single-chain polypeptide, the above nucleic acid, the above vector and the above host cell.

A ninth aspect of the present invention relates to a method for increasing the production of cytokines by the cells having phagocytosis or cytotoxic activity, comprising adding the above diabody-type bispecific antibody to a culture system containing the cells having phagocytosis or cytotoxic activity and tumor cells expressing the human EGF receptors.

#### BRIEF DESCRIPTION OF THE DRAWINGS

Fig.1 shows amino acid sequences of the variable regions of anti-EGFR antibody 528 (SEQ ID NOS: 25 and 26).

Fig.2 is a schematic chart showing the structure of Ex3 expression vectors of pRA-5HOL and pRA-OH5L.

Fig.3 shows photos of SDS-PAGE (upper) and Western-blotting (lower) showing the expression of 5HOL and OH5L in *E. coli* strain BL21.

Fig.4 shows steps of refolding by step-by-step dialysis.

Fig.5 shows the results of binding activity of Ex3 to various cells by Flow Cytometry.

Fig.6 shows the results of inhibition test of Ex3 by Flow Cytometry.

Fig.7 shows the results of absorption test of Ex3 by Flow Cytometry.

Fig.8 are microscopic photos showing the accumulation of T-LAK cells around TFK-1 cells by Ex3.

Fig.9 are microscopic photos showing inhibition of the accumulation by the addition of IgG.

Fig.10 shows the results of in vitro cytotoxicity test (MTS assay) by various diabody-type bispecific antibody such as Ex3.

Fig.11 shows comparison of in vitro cytotoxicity between Ex3 (left bar) and the mixture of each scFv (right bar).

Fig.12 shows the results of in vitro cytotoxicity test ( $^{51}\text{Cr}$  release assay) by the diabody-type bispecific antibody Ex3.

Fig.13 shows the results of in vitro cytotoxicity test ( $^{51}\text{Cr}$  release assay) on various cells by the diabody-type bispecific antibody Ex3.

Fig.14 shows the results of inhibition test by the addition of IgG.

Fig.15 shows increase of the production of IFN- $\gamma$  by the addition of Ex3.

Fig.16 shows increase of the production of GM-CSF by the addition of Ex3.

Fig.17 shows increase of the production of IFNTNF- $\alpha$  by the addition of Ex3.

Fig.18 shows change of the production of IL-2 by the addition of Ex3.

Fig.19 shows time-course change of the production of cytokines.

Fig.20 shows the results of in vivo cytotoxicity test using SCID mouse.

Fig.21 shows amino acid sequences of the variable regions of a humanized antibody OKT3 (SEQ ID NOS: 27 and 28).

Fig.22 shows amino acid sequences of the variable regions of a humanized antibody 528 (SEQ ID NOS: 29 and 30).

Fig.23 is a schematic chart showing the structure of hExh3 expression vectors of pRA-h5HhOL and pRA-hOHh5L.

Fig.24 shows photos of SDS-PAGE (left) and Western blotting (right) showing the expression of h5HhOL and hOHh5L.

Fig.25 shows the results of binding activity of hExh3 to various cells by Flow Cytometry.

Fig.26 shows introduction of a site-specific mutation into h5H (SEQ ID NOS: 25, 29 and 31-40).

Fig.27 shows the results of in vitro cytotoxicity test (MTS assay) by hExh3 and its mutants.

Fig.28 shows the results in vitro cytotoxicity test (MTS assay) indicating concentration-dependency by hExh3 (left bar), its mutants h5H-m09 (middle bar) and Ex3 (right bar).

## BEST MODE FOR CARRYING OUT THE INVENTION

The diabody-type bispecific antibody in the present specification means a small fragment of an antibody having two antigen-binding sites. The fragment contains the variable region of the heavy chain (VH) and the variable region of the light chain (VL) in the same polypeptide chain. In a typical diabody, these two regions (domains) in the same chain are linked together via a linker that is too short to pair the above two domains, so that each domain will be paired with its complementary domain of the other chain to form the two antigen-binding sites together, respectively. With respect to the diabody and techniques for its production, one may refer to US Patent No.4,704,692, US Patent No. 4,946,778, US Patent No.5,990,275, US Patent No.5,994,511, US Patent No.6,027,725, EP No.404,097, WO93/11161, and Hollinger, et al., Proc. Natl. Acad. Sci., USA 90: 6444-6448 (1993), the disclosures of which are incorporated herein by reference, in their entirety to the same content as if each individual patent and document were specifically and individually incorporated by reference.

More specifically, the term “diabody-type bispecific antibody” refers to a fused protein having two different antigen-recognizing functions, consisting of a first polypeptide (i) having in the same peptide chain an antigen-binding site (a) of the variable region of the heavy chain derived from a first antibody and an antigen-binding site (b) of the variable region of the light chain derived from a second antibody, and a second polypeptide (ii) having in the same peptide chain an antigen-binding site (c) of the variable region of the light chain derived from the first antibody and an antigen-binding site (d) of the variable region of the heavy chain derived from the second antibody, as described in Fig.2 of PCT Publication No. WO02/06486.

According to the present invention, the first antibody has the specificity to a human epidermal growth factor (EGF) receptor, and the second antibody has the specificity to the surface antigen expressed by a cell having phagocytosis or cytotoxic activity. As demonstrated by the examples in the present specification, the diabody-type bispecific antibody according to the present invention shows an excellent cytotoxic activity both in vitro and in vivo.

Although there is no limitation with respect to sources or kinds of the antibodies used in the above diabody-type bispecific antibody, they are usually derived from mammals such as human, mouse and rat. Monoclonal antibodies produced by hybridomas are also preferred since they recognize a single antigenic site with a high specificity to it.

Human epidermal growth factor receptor (hEGFR) is a membrane-bound glycoprotein with a molecular weight of about 170 kDa and belongs to EGF family. Four kinds of the hEGFR, i.e., HER-1/Erb1, HER-2/Erb2, HER-3/Erb3 and HER-4/Erb4, have been identified until now. HER-2/Erb2 is expressed in 30-40 % of the adenocarcinoma such as pulmonary carcinoma, gastric carcinoma, colon and rectum carcinomas, breast carcinoma, and ovarian carcinoma. HER-1/Erb1 is expressed in more than 80 % of neck cancer, in 14-91 % of breast cancer, in 40-80 % of non-small cell lung cancer, in 25-77 % of colon and rectum carcinomas, in 30-50 % of pancreatic cancer, in 40-80 % of prostatic cancer, in 35-70 % of ovarian cancer, and in 33-74 % of gastric carcinoma. EGR-EGF receptors are a surface antigen of human cancers or cancer-associated antigen.

The term "human epidermal growth factor receptor" as used herein refers to at least the above four kinds of EGF receptors identified up to now. The antibodies against the human EGFR are already known to those skilled in the art. One of the preferred diabody-type bispecific antibody antibodies according to the present invention has the first specificity to the human EGF receptor 1 (Her1). As one of the antibodies that can provide such specificity, there may be mentioned an anti-human EGF receptor antibody 528 that is produced by mouse B cell hybridoma 528. Accordingly, the first specificity of the diabody-type bispecific antibody according to the present invention is derived from the variable regions in the heavy and light chains of the anti-human EGF receptor antibody 528 (Fig.1).

The term "a cell having phagocytosis or cytotoxic activity" as used herein includes T cells such as NK cell, macrophage, and T-LAK cell, preferably T-LAK cell that is also known as a cytotoxic T cell. The surface antigen expressed by these cells includes CD2, CD3, CD4, CD5, CD6, CD8, CD16, CD28, and CD44, preferably CD3 expressed by the cytotoxic T cell.

The monoclonal antibodies against these surface antigens include those known in the art such as OKT3, T3, Leu4, T11, OKT11, Leu5b, NU-T1, OKT4, Leu3a, NU-TH/I, T8, OKT8, Leu2a and NU-Ts/c, preferably OKT3, T3 and Leu4. Accordingly, the second specificity of the diabody-type bispecific antibody according to the present invention is derived from the variable regions in the heavy chain and the light chain of anti-CD3 antibody OKT3.

In addition to the above commercially available antibodies, the antibodies that will provide the variable regions of the diabody-type bispecific antibody according to the present invention can be prepared by various methods well known in the art with use of the human EGFRs or the cells having phagocytosis or cytotoxic activity as an immunogen.

For example, polyclonal antibodies may be produced in the body of animals such as mouse by subcutaneously or intraperitoneally injecting the immunogen in the animals several times optionally in combination with an adjuvant.

On the other hand, monoclonal antibodies may be obtained from a substantially homogeneous population in accordance with a method first described in Kohler & Milstein, *Nature* 256: 495 (1975), or alternatively by means of a recombinant DNA technique (US Patent No.4,816,567).

Furthermore, human antibodies may be prepared in the body of a transgenic animal (e.g., mouse). Please refer to, for example, Duchosal et al., *Nature* 355:258 (1993); Jakobovits et al., *Proc. Natl. Acad. Sci. USA* 90:2551 (1993); Jakobovits et al., *Nature* 362:255-258 (1992); Brugermann et al., *Year in Immunol.* 7:33 (1993). Human antibodies may be also derived from phage display libraries (Marks et al., *J. Mol. Biol.* 222:581-597 (1991); Hoogenboom et al., *J. Mol. Biol.* 227:381 (1991); Hoogenboom et al., *Immunol. Rev.* 130:41-68 (1992); Vaughan et al., *Nature Biotech.* 14:309 (1996)).

The above antibodies and the fragment thereof may be further isolated from antibody phage library in accordance with the technique described in Cafferty et al., *Nature*, 348:552-554 (1990). Clackson et al., *Nature*, 352:624-628 (1991) and Mark et al., *J. Mol. Biol.* 222:581-597 (1991) disclose the isolation of mouse and human antibody from the phage library, respectively. The above antigens may be used to

select an appropriate antibody or fragment thereof. Other techniques known to those skilled in the art may be optionally used in the present invention, which include chain shuffling method to produce a human antibody with a high affinity (the order of nM) (Mark et al., Bio/Technol. 10: 779-783 (1992), combinatorial infection and in vivo recombination method to construct a very large phage library (Waterhouse et al., Nuc. Acids Res., 21:2265-2266 (1993).

The diabody-type bispecific antibody according to the present invention may comprise a linker that links the variable region of the heavy chain (VH) and the variable region of the light chain (VL) with each other. The term "linker" as used herein refers to an oligopeptide or polypeptide that combines VH and VL together to give a single-chain polypeptide. The linker is preferably a peptide linker. Any linker known in the art or modified therefrom may be optionally selected and used in the present invention as long as it can operably combine the two polypeptides together to give the single-chain polypeptide. The peptide linker according to the present invention may have about 1-50 amino acids, preferably about 2-30 amino acids, more preferably about 2-20 amino acids. The term "operably combine" as used herein refers to an appropriate folding of the polypeptide to give a fused protein having such a three-dimensional structure as to mimic the function of the original protein (the function derived from the original polypeptide or protein) such as all or part of its biological activity.

The length of the linker is selected so as to give a desired activity to the single-chain polypeptide or fused protein while depending on their properties. The linker, however, should be long enough to fold the resulting single-chain polypeptide so as to give the desired biological activities. The length of the linker may be experimentally determined by testing a series of single-chain polypeptides prepared by using linkers with different lengths. The documents listed above with respect to the diabody and techniques for its production may be referred to for the linker as well.

The VH region and VL region may be arbitrarily allocated in the single-chain polypeptide, including VL(N-end)-Linker-VH(C-end) construct and VH (N-end)-Linker-VL (C-end) construct.

The diabody-type bispecific antibody according to the present may be humanized. The humanized antibody is clinically very advantageous since its potentiality of acting as immunogenicity upon administration into human body has been lowered by using the regions with specific reactivity that is derived from mouse antibodies and the like, and the other regions that are derived from human antibodies.

The term "humanized antibody" as used herein means a human immunoglobulin (a recipient antibody) in which at least part of the residues of complementary-determining region (CDR) is replaced with residues derived from the CDR of a non-human animal antibody (a donor antibody) that has a desired specificity, affinity and capability, such as those of mouse, rat, and rabbit. In some cases, the residue(s) of a Fv framework (FR) in the human immunoglobulin is replaced with residue(s) of the corresponding non-human antibody. The humanized antibody may further comprise a residue that is not found in the recipient antibody or the introduced CDR or framework. These changes are made in order to optimize or improve the properties of the resulting antibody. More detailed information on these changes are referred to Jones et al., Nature 321, 522-525 (1986); Reichmann et al., Nature 332, 323-329 (1988); EP-B-239400; Presta, Curr. Op. Struct. Biol 2, 593-596 (1992); and EP-B-451216.

The humanized antibody may be prepared in accordance with any methods known to those skilled in the art, for example, by analyzing various conceptual humanized preparations based on three-dimensional immunoglobulin models of the recipient antibody and donor antibody, and analyzing them. The three-dimensional immunoglobulin models are well known in the art, being referred to, for example, WO92/22653.

Thus, one example of the humanized diabody-type bispecific antibody according to the present invention is that wherein the complementary determining region (CDR) in the variable regions are derived from a mouse antibody, and the other parts are derived from a human antibody. One preferable example is therefore a diabody-type bispecific antibody having at least one CDR selected from the amino acid sequences of CDR1, CDR2 and CDR3 in the variable regions derived

from a humanized anti-CD3 antibody OKT3 represented in Fig.21 and having at least one CDR selected from the amino acid sequences of CDR1, CDR2 and CDR3 in the variable regions derived from a humanized anti-human EGF receptor antibody 528 represented in Fig.22.

More preferable example is a diabody-type bispecific antibody, wherein the variable regions in the heavy chain and light chain derived from the humanized anti-CD3 antibody OKT3 have an amino acid sequence represented in Fig.21 (SEQ ID No.27 and 28) and, the variable regions in the heavy chain and light chain derived from the humanized anti-human EGF receptor antibody 528 have an amino acid sequence represented in Fig.22 (SEQ ID No.29 and 30).

The activity or function of the resulting antibody may be deteriorated due to the humanization. The activity or function of the diabody-type bispecific antibody according to the present invention may be therefore improved by being provided with a site-specific mutation at an appropriate position in the single-chain polypeptide, for example, at a position in the framework which can affect the CDR structure, such as in canonical sequence or veriner-vernier sequence. The antibody obtained by such site-specific mutation is included in the diabody-type bispecific antibody according to the present invention.

As described above, the diabody-type bispecific antibody according to the present invention consists of two kinds of the single-chain polypeptides. The present invention relates therefore also to each single-chain polypeptide and to a polypeptide constituting each region (for example, the variable region derived from each antibody) contained in the single-chain polypeptide. The single-chain polypeptide has the variable region in the heavy chain derived from a first (or second) antibody, the variable region in the light chain derived from a second (or first) antibody and the linker binding them to each other. It may further optionally contain bacterial enterotoxin such as staphylococcus enterotoxin, E. coli enterotoxin, cholera enterotoxin, and their derivatives. Various peptide tags (c-myc and His-tag, for example) known in the art may be contained at its end, etc.

However, it is well known that these super antigens may possibly cause cytokine-dependent toxin shock syndromes due to their strong affinity towards

MHC\_class II. On the contrary, the diabody-type bispecific antibody according to the present invention shows remarkably high cytotoxic activity even without such super antigen, and advantageously avoids the above potential risk due to the super antigen.

In accordance with a method known to those skilled in the art, a nucleic acid encoding the single-chain polypeptide or each region contained therein may be obtained, and its base sequence may be determined, by using, for example, an oligonucleotide probe specifically binding to a gene encoding the heavy and light chains of the mouse antibody (R. Orlandi et al., Proc. Natl. Acad. Sci., USA 86: 3833-3837 (1993)). The hybridomas producing the above monoclonal antibodies may be used as DNA source in these methods.

More specifically, the nucleic acid encoding the single-chain polypeptide may be prepared by replacing VH or VL in a single-chain Fv (or "scFv") already constructed and known in the art or in a known diabody-type bispecific antibody with another VH or VL derived from an antibody having different specificity. The term "scFv" as used herein means a single-chain polypeptide having VH domain and VL domain of an antibody within a single-chain polypeptide. Usually the scFv polypeptide has a linker between the two domains in order to give a structure necessary for showing antigen-binding activity. Rosenburg and Moore (Ed.), "The Pharmacology of Monoclonal Antibodies," Vol.113, Springer-Verlag, New York pp.269-315 (1994) may be referred to with respect to scFv.

Furthermore, the nucleic acid encoding the variable regions in the single-chain polypeptide of the diabody-type bispecific antibody may be synthesized by means of an overlapping PCR method based on a pre-determined amino acid sequence. The nucleic acid used herein has no limitation in its chemical structure or preparation route, as long as it is a molecule encoding the single-chain polypeptide, including gDNA, cDNA chemically-synthesized DNA and mRNA.

Specifically, the nucleic acid according to the present invention may be isolated from cDNA library by means of hybridization or PCR based on the sequences disclosed in literatures. The thus isolated DNA may be inserted in an expression vector, with which a host cell such E. coli, COS cell, CHO cell or

myeloma not expressing immunoglobulin are transfected to synthesize a monoclonal antibody in the thus transformed host cells.

PCR may be carried out in accordance with a method known in the art, or substantially the same or altered methods. The methods disclosed in, for example, R. Saiki, et al., *Science*, 230:1350, 1985; R. Saiki, et al., *Science*, 239:487, 1988; H. A. Erlich ed., *PCR Technology*, Stockton Press, 1989; D.M. Glover et al., ed., "DNA Cloning," 2<sup>nd</sup>. ed., Vol.1, (*The Practical Approach Series*), IRL Press, Oxford University Press (1995); M.A. Innis et al., ed., "PCR Protocols: a guide to methods and applications," Academic Press, New York (1990); M.J. McPherson, P. Quirke and G.R. Taylor (Ed.), *PCR: a practical approach*, IRL Press, Oxford (1991); M.A. Frohman et al., *Proc. Natl. Acad. Sci. USA*, 85, 8998-9002 (1988), and their modified and altered methods may be used in the present invention. PCR may be performed with use of a commercially available kit in accordance with manufacturer's protocols.

Hybridization may be referred to L. Grossman et al. (ed.), "Methods in Enzymology", Vol.29 (Nucleic Acids and Protein Synthesis, Part E), Academic Press, New York (1974). The sequencing method of nucleic acids such as DNA may be referred to Sanger et al., *Proc. Natl. Acad. Sci. USA* 74:5463-5467 (1977). A general method for recombinant DNA techniques may be referred to J. Sambrook, E. F. Fritsch & T. Maniatis (ed.), "Molecular Cloning: A Laboratory Manual (2<sup>nd</sup> edition)", Cold Spring Harbor Laboratory Press, Cold Spring Harbor, New York (1989) and D.M. Glover et al. (ed.), 2<sup>nd</sup> ed., Vol.1 to 4 (*The Practical Approach Series*), IRL Press, Oxford University Press (1995).

The nucleic acid encoding the single-chain polypeptide or each region contained therein may be modified or altered so that it will optionally encode a desired peptide or amino acid depending on the purpose. The techniques for such modification or alteration are disclosed in *Mutagenesis: a Practical Approach*, M.J. McPherson (ed.), IRL Press, Oxford, UK (1991), including a site-specific mutagenesis introduction method, cassette mutagenesis induction method and PCR mutagenesis method.

The term "modification (or alternation)" as used herein refers to insertion, deletion or substitution of base(s) in at least one codon encoding an amino acid residue in the originally obtained nucleic acid. It includes alternation of the amino acid sequence per se of the single-chain polypeptide by replacing a codon encoding the original amino acid with a codon encoding another amino acid. The single-chain polypeptide constituting the humanized diabody-type bispecific antibody may be obtained in this way.

Alternatively, the nucleic acid encoding the single-chain polypeptide may be altered without changing the amino acid per se, by using a codon suitable for a host cell (an optimum codon). With the use of the optimum codon, expression efficiency of the single-chain polypeptide in the host cell will be improved.

The linker and super antigen may be optionally introduced into the single-chain polypeptide constituting the diabody-type bispecific antibody according to the present invention by means of any techniques well known in the art such as genetic engineering technique including recombinant technology and chemical synthesis of peptides.

The single-chain polypeptide may be produced by various methods well known in the art such as genetic engineering technique and chemical synthesis. The genetic engineering technique includes constructing a replicable cloning vector or expression vector, transforming the host cell with the vector, culturing the transformed host cell to express the nucleic acid in it, collecting and purifying the single-chain polypeptide. The vector usually comprises the nucleic acid encoding one of the two single-chain polypeptides constituting the diabody-type bispecific antibody according to the present invention. In such case, the resulting two kinds of the vectors are preferably introduced into the same host cell. Alternatively, the two kinds of nucleic acid encoding the different single-chain polypeptide from each other may be comprised in the same vector.

The term "replicable expression vector" or "expression vector" as used herein refers to a piece of DNA (usually double-stranded) that may comprise a fragment of a foreign DNA fragment inserted therein. The foreign DNA is also defined as a "heterologous DNA", which can not be found naturally in a host cell in

interest. The vector is used to carry or convey the foreign or heterologous DNA into an appropriate host cell. Once the vector is introduced into the host cell, it may be replicated independently from a chromosomal DNA of the host cell to produce copies of the vector and foreign DNA inserted therein. The vector also comprises elements essential for translating the foreign DNA into a polypeptide so that the polypeptide molecules encoded by the foreign DNA will be synthesized very quickly.

The above vector means a DNA construct comprising an appropriate control sequence and DNA sequence that are operably linked together (i.e., linked together so that the foreign DNA can be expressed). The control sequence includes a promoter for transcription, an optional operator sequence to regulate the transcription, a sequence encoding an appropriate mRNA ribosome-biding site, an enhancer, a polyadenylation sequence, and a sequence controlling the termination of transcription and translation. The vector may further comprise various sequences known in the art, such as a restriction enzyme cleaving site, a marker gene (selection gene) such as a drug-resistant gene, a signal sequence, and a leader sequence. These sequences and elements may be optionally selected by those skilled in the art depending on the kinds of the foreign DNA and host cell, and conditions of culture medium.

The vector may be in any form such as a plasmid, phage particle, or just simply genomic insert. Once the appropriate host cell is transformed with the vector, the vector will be replicated or function independently from the genome of the host cell, or the vector will alternatively be integrated into the genome of the cell.

Any cell known in the art may be used as the host cell, for example, there may be mentioned procaryotic cells such as including E. coli., eucaryotic cells such as mammalian cells such Chinese hamster ovary (CHO) cell and human cells, yeast, and insect cells.

Although the single-chain polypeptide obtained by the expression in the host cell is usually secreted and collected from the culture medium, it may be also collected from cell lysate when it is directly expressed without a secretion signal.

In case the single-chain polypeptide has a membrane-binding property, it may be released from the membrane with an appropriate surfactant such as Triton-X100.

Purification of the polypeptide may be carried out by any method known to those skilled in the art such as centrifugation, hydroxyapatite chromatography, gel electrophoresis, dialysis, separation on ion-exchange chromatography, ethanol precipitation, reverse phase HPLC, silica chromatography, heparin-sepharose chromatography, anion- or cation-resin chromatography such as polyaspartic acid column, chromato-focusing, SDS-PAGE, precipitation with ammonium sulfate, and affinity chromatography. The affinity chromatography, which utilizes affinity with a peptide tag of the single-chain polypeptide, is one of the preferred purification techniques with a high efficiency.

Since the collected single-chain polypeptide may be often included in an insoluble fraction, the polypeptide is preferably purified after being solubilized and denatured. The solubilization treatment may be carried out with the use of any agent known in the art, including alcohol such ethanol, a dissolving agent such as guanidine hydrochloride and urea.

The diabody-type bispecific antibody according to the present invention is produced by assembling the single-chain polypeptides, and separating and collecting the thus formed diabody-type antibody.

Assembling treatment brings the single-chain polypeptide back in an appropriate spatial arrangement in which a desired biological activity is shown. Thus, since this treatment brings the polypeptides or domains back into an assembling state, it may be considered "re-assembling." It may be also called "re-constitution" or "refolding" in view of gaining the desired biological activity.

The assembling treatment may be carried out by any method known in the art preferably by gradually lowering the concentration of a denaturing agent such as guanidine hydrochloride in a solution comprising the single-chain polypeptide by means of dialysis. During these processes, an anti-coagulant or oxidizing agent may be optionally added in a reaction system in order to promote the oxidation. The separation and collection of the formed diabody-type bispecific antibody may be done by any method known in the art as well.

A pharmaceutical preparation according to the present invention comprises an active ingredient selected from the group consisting of the diabody-type bispecific antibody, especially the humanized one, the single-chain polypeptide, the nucleic acid, the vector, and the host cell described in the above. As shown by the examples in the present specification, since the active ingredient has an activity of eliminating, hurting, damaging and/or reducing tumor cells expressing EGFR in vitro and in vivo, the present pharmaceutical preparation is used as an anti-tumor agent.

Furthermore, it is demonstrated by the examples in the present specification that co-existence of the diabody-type bispecific antibody with the tumor cells expressing human EGFR and the cells having phagocytosis or cytotoxic activity in vitro or in vivo will increase the production of cytokines such as IFN- $\gamma$ , GM-CSF, and ~~TFNTNF~~- $\alpha$  by the cells having phagocytosis or cytotoxic activity. The pharmaceutical preparation according to the present invention may be therefore used for the above purposes as well. In vitro, for example, the addition of the diabody-type bispecific antibody to a culture system comprising the above two kinds of the cells will increase the production of the cytokines.

An effective amount of the active ingredient may be optionally determined by those skilled in the art depending on the purpose of treatment, medical conditions of a patient to be treated such as kind, site or size of tumor, and administration route. A typical dose or daily dose may be first determined in vitro by using an assay method of growth or existence of the tumors known in the art, then determined with use of such an appropriate animal model as to allow extrapolation of the resulting dose range to human patients.

The pharmaceutical preparation of the present invention may optionally comprise various kinds of pharmaceutically acceptable components known in the art such as carrier, excipient, buffer, stabilizing agent and the like, depending on various factors such as the kind of the active ingredients, its formulation form, the route and purpose of administration, medical conditions of patient.

The pharmaceutical preparation of the present invention may be formulated into any form such as pill, liquid, powder, gel, air spray, microcapsule, and colloidal dispersion (liposome, micro emulsion, etc.).

The pharmaceutical preparation may be administered by injecting or infusing ~~intraveneously~~ intravenously, intraperitoneally, intracerebrally, intraspinally, intramuscularly, intraocularly, intraarterially, especially intrabiriarily, or via diseased tissue, or with use of a constant releasing agent system. The active ingredient according to the present invention may be administered through continuous fluid infusion or massive injection. The pharmaceutical preparation according to the present invention is preferably administered in combination with the cell having phagocytosis or cytotoxic activity. Alternatively, the active ingredient such as the diabody-type bispecific antibody may be mixed with the above cells so as to bind to them before its administration.

The constant releasing agent generally refers to a formulation that can release the active ingredient of the present invention for a certain period of time. One of the preferred constant releasing agents comprises a semi-permeable carrier of solid hydrophobic polymer such as protein, which is shaped into a form such as film or micro capsule.

The pharmaceutical preparation according to the present invention may be produced by a method that is optionally selected from, for example, "Guide Book of Japanese Pharmacopoeia", Ed. of Editorial Committee of Japanese Pharmacopoeia, Version No.13, published July 10, 1996 by Hirokawa publishing company

The terms as used in the present specification and drawings are based on IUPAC-IUB Commission on Biochemical Nomenclature or on meanings of the terms conventionally used in the art.

The present invention will be explained more in detail by referring to the Examples, which are provided only for describing the specific embodiments of the present invention, but not for limiting the scope of the present invention. It is therefore to be understood that various embodiments based on the inventive concept of the present specification may be practiced within the scope of the present invention.

The following examples were or can be carried out with standard techniques well known to those skilled in the art unless otherwise described. Thus, unless otherwise described, specific procedures and treating conditions are in accordance with J. Sambrook, E. F. Fritsch & T. Maniatis, "Molecular Cloning", 2nd ed., Cold Spring Harbor Laboratory, Cold Laboratory, Cold Spring Harbor, N. Y. (1989) and D. M. Glover et al. ed., "DNA Cloning", 2nd ed., Vol. 1 to 4, (The Practical Approach Series), IRL Press, Oxford University Press (1995) (DNA cloning), and with H. A. Erlich ed., PCR Technology, Stockton Press, 1989 ; D. M. Glover et al. ed., "DNA Cloning", 2nd ed., Vol. 1, (The Practical Approach Series), IRL Press, Oxford University Press (1995) and M. A. Innis et al. ed., "PCR Protocols", Academic Press, New York (1990) (PCR) . A commercially available agent and kit were used in accordance with protocols attached thereto.

#### Examples

##### Example 1: Cloning of Anti-Epidermal Growth Factor Receptor Antibody

Mouse B cell hybridoma 528 producing anti-EGFR antibody was provided by Cell Resource Center for Biomedical Research, Institute of Development, Aging and Cancer.

Of TOHOKU University, mRNA was extracted with ISOGEN (Nippon Gene Co.) and then cDNA was prepared by means of First-Strand cDNA Synthesis Kit (Amersham Biosciences Co.). PCR reaction was done for the cDNA using cloning primers that were synthesized based on Reference 1 to determine the sequences of variable regions of 528, VH (referred to as "5H") and VL (referred to as "5L")( Fig.1).

Reference 1: Kr ebber, A. et al. Reliable cloning of functional antibody variable domains from hybridomas and spleen cell repertoires employing a reengineered phage display system. J Immunol Methods 201, 35-55. (1997).

### Example 2: Preparation of Ex3 diabody-expressing vector

A representative example of the diabody-type bispecific antibody according to the present invention, Ex3 diabody (referred to as "Ex3"), consists of two molecules, i.e., "5HOL" and "OH5L." The expression vector was prepared based on the expression vector for Mx3 diabody (referred to as "Mx3") that was already constructed by the inventors and has specificity to MUC1 and CD3 (PCT Publication No. WO02/06486). Thus, "5H" was amplified with PCR using A·B primers comprising a restriction enzyme site, digested with NcoI·EagI, and was replaced with "MH" in pSNE4-MHOL (VH of anti-MUC1 antibody (MUSE11) (referred to as "MH") – GGGGS (referred to as "G1") – VL of anti-CD3 antibody OKT3 (referred to as "OL") to give pRA-5HOL. Similarly, "5L" was amplified with PCR using C·D primers comprising a restriction enzyme site, digested with EcoRV·SacII, and was replaced with "ML" in pSNE4-OHML (VH of OKT3 (referred to as "OH") – "G1" – VL of MUSE11 (referred to as "ML") to give pRA-OH5L (Fig.2). A c-myc peptide tag for detection and a His-tag (His<sub>x</sub>6:histidine-hexamer) for purification were introduced successively into the vectors.

A *NcoI*-5H back primer        5'-nnnccatggcccagggtccagtcgcagcagtctg-3'

[SEQ ID No.1]

B 5H-*EagI* forward primer        5'-nnncggccgaggagactgtgagagtgg-3'

[SEQ ID No.2]

C *EcoRV*-5L back primer        5'-nnngataatctaattgacccaatctcc-3'

[SEQ ID No.3]

D 5L-*SacII* forward primer        5'-nnnccgcggcacgttgatttccagcttg-3'

[SEQ ID No.4]

### Example 3: Expression of "5HOL" and "OH5L" by E. coli

Each E. coli BL21 strain (E3) was transformed with the expression vector pRA-5HOL and pRA-OH5L, respectively, and cultured in 2 x YT medium at 28°C. When O.D.<sub>600</sub> reached about 0.8, expression was induced by the addition of IPTG to a final concentration of 1mM and cultured overnight under shaking. The resulting

bacteria were separated from culture supernatant by centrifugation, crushed with ultrasonic wave and subjected again to centrifugation to obtain supernatant as a soluble fraction within the bacteria cell and precipitate as an insoluble fraction within the bacteria cell. Since SDS-PAGE and Western-blotting of each fraction revealed that almost all of the “5HOL” and “OH5L” was contained in the insoluble fraction within the bacteria cell, these proteins were then prepared from said insoluble fraction (Fig.3, lanes 1 & 5: culture supernatant; lanes 2 & 6: soluble fraction within the bacteria cell; lanes 3 & 7: insoluble fraction within the bacteria cell; lane 4: after purification and refolding).

Example 4: Purification and Refolding of “5HOL” and “OH5L”

After being solubilized by soaking the insoluble fraction within the bacteria cell into 6M guanidine hydrochloride/PBS overnight at 4°C, the proteins were purified by means of metal-chelate affinity chromatography using a metal-chelate resin (TALON™: CLONTECH Co.) having specificity to His-Tag in a denatured state. Yield of each protein after the purification was about 5 mg per 1L of culture medium of the transformed cells, respectively.

Since the thus purified proteins were in the denatured state due to guanidine hydrochloride, it was necessary to refold them in order to obtain a three-dimensional structure maintaining the activity. After being diluted to 7.5μM, both the “5HOL” and “OH5L” proteins in the same quantity were mixed together (the total protein concentration:7.5 μM and Ex3 concentration:3.75 μM). 2-mercaptoethanol ( $\beta$ -ethane<sub>1</sub>Me) in a 50-fold amount of the total proteins was then added to a final concentration of 375 μM, and the proteins were kept standing still for 4 hours at 4°C for a reductive reaction. After the reaction sample was put into a dialysis membrane, it was subjected to step-by-step (or gradual) dialysis for removing the denaturing agent by gradually reducing the concentration of guanidine hydrochloride in an outer liquid, i.e., 3M (6hr), 2M (6hr), 1M (12hr), 0.5M (12hr) and 0M. At the stage of the concentration of 1M and 0.5M during the step-by-step dialysis, an oxidant of oxidized glutathione (GSSG) and an anti-coagulant of L-arginine (L-Arg) were added in the outer liquid to a final

concentration of 375  $\mu$ M and 0.4 M, respectively and the reaction mixture was kept at 4°C for promoting oxidization (Fig.4). The efficiency of refolding was about 30%. SDS-PAGE of the Ex3 obtained by the purification and the mixture of the same quantity of the “5HOL” and “OH5L” followed by refolding confirmed that they were purified with a very high degree and they had formed a homogeneous hetero-dimer (Fig.3).

#### Example 5: Evaluation of Ex3 (1) – Flow cytometric analysis

The binding activity of Ex3 to various cells was examined with Flow cytometry. Target cells were mixed with a first antibody of Ex3 of 100 $\mu$ L, left to stand still for 30 min. at 4°C, washed twice with 0.1 % NaN<sub>3</sub>/PBS, mixed with a second antibody of anti-c-myc antibody followed by the same procedures, and finally mixed with a third antibody of FITC-labeled anti-mouse antibody followed by the same procedures, and subjected to the detection of fluorescence. For a negative control, only the procedures after the addition of the second antibody were repeated. On the other hand, OKT3 IgG and 528 IgG were used for a positive control (referred to as “PC”) in T-LAK cell and TFK-1 cell (human bile duct biliary caneercarcinoma cell strainline), respectively. The results showed that Ex3 could bind to both the cells (Fig.5, upper).

Stability was examined by still standing for 48 hours under physiological conditions (37°C, RPMI 1640 medium) followed by the same procedures to confirm that there was no substantial change in the binding activity (Fig.5, lower).

In order to examine whether or not the recognition site of Ex3 was the same as that of each parent antibody, the same procedures as in the case of PC were repeated after the addition of Ex3 (20 $\mu$ g), and inhibition of the parent antibodies of OKT3 IgG (0.1 $\mu$ g) and 528 IgG (0.25 $\mu$ g) was examined. The results showed that binding ability of the parent antibodies was decreased, indicating that the recognition sites of Ex3 and its parent antibodies were the same with each other (Fig.6, the left (OKT3 IgG) and the right (528 IgG)).

Absorption test, in which after the reaction of Ex3 with an excess amount of T-LAK cell (upper,  $5 \times 10^6$ ) or TFK-1 cell (lower,  $5 \times 10^6$ ), each cell was treated with

the resulting supernatant and subjected to Flow cytometry, showed that the binding ability was decreased in any combination. These results indicated that a single Ex3 molecule bound to both the cells, i.e., Ex3 had bispecificity (Fig.7).

Example 6: Evaluation of Ex3 (2) – Microscopic observation

After cancer cells were cultured overnight while being attached, they were mixed with T-LAK cells alone or in combination with Ex3, and microscopically observed in time course. While substantial no change was observed even after 12 hours in the case of the addition of T-LAK cells alone, T-LAK cells started to accumulate around the cancer cells after 2 hours and almost all of them was accumulated around the cancer cells after 12 hours in a plate wherein Ex3 was mixed in addition to T-LAK cells (Fig.8). The term “E/T” or “Effector/Target” as used in a drawing attached to the present specification means the ratio of “effector (T-LAK cell)/target (TFK-1 cell).”

Further, in an inhibition test, while plates to which the parent antibody OKT3 or 528 IgG was added showed almost no accumulation of the T-LAK cells after 18 hours, plates to which OKT8 (anti-CD8 antibody) or MUSE11 (anti-MUC1 antibody) IgG having no relevance to the system showed almost the same accumulation as in the case of not being added (Fig.9).

Example 7: Evaluation of Ex3 (3) – In vitro Cytotoxicity Test (MTS assay)

The degree of damage in TFK-1 cell due to T-LAK cell was determined by MTS assay. TFK-1 cell sample was adjusted to contain  $10^4$  cells per  $100\mu\text{L}$  of RPMI 1640 by counting the cell, and its aliquot of  $100\mu\text{L}$  was dispensed into each well of a 96-well plate to stand still overnight at  $37^\circ\text{C}$ . After being diluted with RPMI to a desired concentration of the protein according to the present invention,  $50\text{-}\mu\text{L}$  of which was put into each well of the above plate. LAK cell was diluted with RPMI to a desired E/T ratio, and  $50\text{-}\mu\text{L}$  of which was put into each well of the above plate as well. After being cultured for 48 hours at  $37^\circ\text{C}$ , the cells were removed from culture medium, washed with PBS, mixed with MTS (CellTiter 96 AQueous Non-Radioactive Cell Proliferation Assay, Promega Co.), PMS (CellTiter

96 AQueous Non-Radioactive Cell Proliferation Assay, Promega Co.), and RPMI, and incubated for 30-60 min. at 37°C, followed by the detection of absorbance at 490 nm with a plate reader. It was observed that Ex3 showed much stronger effects than Mx3 or mSEA·Mx3. The concentration of Ex3 required to kill 100 % of TFK-1 cells was as low as 1pmol/mL (ca. 60ng/mL), which was about 100 times lower than that of mSEA·Mx3 (Fig.10).

On the other hand, an equimolar mixture of OKT3 scFv and 528 scFv did not show any cytotoxic effect even at a high concentration. These results showed that it was important to physically bridge lymphocytes and cancer cells, i.e., to get them close together by the bispecific antibody in addition to the effects by each antibody per se, i.e., the activation of T-LAK through the stimulation of CD3 by OKT3, and growth inhibition of TFK-1 due to the blocking of EGFR by 528,

#### Example 8: Evaluation of Ex3 (4) – In vitro Cytotoxicity Test (<sup>51</sup>Cr release assay)

Although MTS assay could easily examine the cytotoxicity in vitro, it detected only growth inhibition of the attached cancer cells. <sup>51</sup>Cr release assay was then carried out, which could detect directly the cytotoxicity. The results showed a significant cytotoxicity due to the addition of Ex3, which would increase depending on the increase of the E/T ratio. PBMC (peripheral blood mononuclear cell) would be used instead of the lymphocytes that have activated ex vivo such as T-LAK cell in an adoptive immunotherapy. The increase of the cytotoxicity was also observed depending on the increase of the E/T ratio even with the use of PBMC as an effector cell.

The increase of the cytotoxicity due to the existence of Ex3 depending on the increase of the E/T ratio was observed for other EGFR (Her1)-positive biliary pancreatic duct carcinoma cells as well (Fig.13). On the other hand, the addition of Ex3 did not increase the cytotoxicity of T-LAK cell for EGFR (Her1)-negative cells (Table 1).

Further, in an inhibition test, while the addition of the parent antibodies OKT3 or 528 IgG showed the decrease of cytotoxicity, the addition of OKT8 or MUSE11 IgG that had no relevance to the system did not show any (Fig.14).

The abbreviations for the terms used in Table 1 and drawings are as follows.

TFK-1: human biliary-bile duct adenocarcinoma;  
OCUCH-LM1: human bile ductbiliary carcinoma;  
HuCC-T1: human bile ductbiliary carcinoma;  
OBA-LK1: human lung large cell carcinoma;  
A549: human lung adenocarcinoma;  
CRL1500: human breast carcinoma;  
SK-BR-3: human breast adenocarcinoma;  
A431: human epidermoidepidermal carcinoma;  
MCF-7: human breast adenocarcinoma;  
NCI-H69: human lung small cell carcinoma;  
CHO: Chinese hamster ovarian earcineomacell.

[Table 1]

6hr  $^{51}\text{Cr}$  release assay (E/T=25)

target cells	T-LAK alone (A)	Ex3 diabody 1 $\mu\text{g}/\text{ml}$ (B)	enhancement of cytotoxicity (B/A)	origin
<b><i>EGFR positive</i></b>				
TFK-1	29.00 $\pm$ 0.86	76.39 $\pm$ 0.86	2.64 $\pm$ 0.04 ***	bile duct
OCUCH-LM1	21.93 $\pm$ 0.57	64.96 $\pm$ 0.33	2.96 $\pm$ 0.04 ***	bile duct
HuCC-T1	15.15 $\pm$ 0.79	63.78 $\pm$ 0.30	4.23 $\pm$ 0.11 ***	bile duct
OBA-LK	44.09 $\pm$ 0.75	87.11 $\pm$ 2.26	1.98 $\pm$ 0.03 ***	lung (large cell carcinoma)
A549	14.15 $\pm$ 2.61	66.84 $\pm$ 4.68	5.14 $\pm$ 0.60 ***	lung (adenocarcinoma)
CRL1500	8.91 $\pm$ 1.07	45.23 $\pm$ 2.90	5.22 $\pm$ 0.35 ***	breast
SK-BR-3	39.92 $\pm$ 1.18	84.18 $\pm$ 8.06	2.11 $\pm$ 0.11 *	breast
A431	15.99 $\pm$ 1.99	81.23 $\pm$ 6.28	5.22 $\pm$ 0.36 ***	epidermoid cancer
<b><i>EGFR negative</i></b>				
MCF-7	16.83 $\pm$ 0.67	10.59 $\pm$ 0.35	0.62 $\pm$ 0.02 **	breast
NCI-H69	54.95 $\pm$ 2.28	46.27 $\pm$ 4.53	0.84 $\pm$ 0.04	lung (small cell carcinoma) <i>other species</i>
CHO-K1	42.92 $\pm$ 5.22	49.13 $\pm$ 2.41	1.18 $\pm$ 0.08	chinese hamster ovarian cell

\*\*;p&lt;0.01, \*\*\*;p&lt;0.001, \*\*\*\*; p&lt;0.0001

#### Example 9: Evaluation of Ex3 (5) – Secretion of various cytokines

The production amounts of various cytokines were determined in order to identify a factor responsible for the increase of the cytotoxicity of T-LAK cell. TFK-1 cells were attached to a plate and left to stand still overnight, to which T-LAK cells alone and in combination of Ex3 with various concentrations were then added, followed by the detection of the amounts of cytokines in culture supernatant by means of ELISA kit (ENDOGEN Co.) after 48 hours. While no remarkable increase in IFN- $\gamma$  production was observed in the plates to which T-LAK cell, T-LAK cell plus Ex3, or T-LAK cell plus TFK-1 cell were added, the increase in IFN- $\gamma$  production was observed in a concentration-dependent manner by the addition of Ex3, T-LAK cell and TFK-1 cell. The addition of the parent antibody OKT3 or 528 IgG showed inhibition effect, but not induced the production of IFN- $\gamma$  (Fig.15).

The similar results were obtained with respect to GM-CSF and TNF- $\alpha$  (Fig.16 & 17). However, there was not increase in the concentration-dependent manner, but a slight decrease in the production of IL-2 (Fig.18).

Changes in time course in the production of various cytokines were determined by means of ELISA. While the production off IFN- $\gamma$  and GM-CSF were increased in time course in the concentration-dependent manner, the production of TNF- $\alpha$  and IL-2 reached their highest levels in 12 hours and then decreased drastically. It was considered that the target cells, TFK-1, died 12 hours later, incorporated and digested by T-LAK cells without producing IL-2 and the like any more (Fig.19). This assumption seems to coincide well with the results shown in Fig.18.

#### Example 10: Evaluation of Ex3 (6) – In vivo Cytotoxicity Test

SCID mice were injected subcutaneously with  $5 \times 10^6$  of TFK-1 cells ten and several days after they had been taken. Ten days after the grafting of the TFK-1 cells (diameter of the tumor was about 4-6 mm), the mixture of  $2 \times 10^7$  of T-LAK cells and each antibodies was injected intravenously at a tail of the mice for consecutive 4 days. The diameter of the tumor was measured every one week, and the volume

of the tumor was estimated from its major axis and minor axis. This test was stopped when the diameter of the tumor in a control went beyond 20 mm.

The results clearly showed that while the tumor kept growing in a group administered with T-LAK cells alone and the control group administered with PBS, the growth of the tumor was remarkably inhibited in a group administered with Ex3. Especially, the tumor in a group administered with 20 $\mu$ g/mouse was degenerated in almost the same degree as in a group administered with chemically-synthesized Ex3 bsAb (Fig.20).

#### Example 11: Preparation of Humanized Ex3 Gene

It was already reported that the variable region of the humanized OKT3 could maintain its activity when compared with the mouse OKT3 (Reference 2). The total gene was synthesized by means of overlapping PCR based on the amino acid sequence of the variable regions of the humanized OKT3 disclosed in the Reference 2 (Fig.21). The optimum codons for *E. coli* were used in the synthesis. It was also reported that the use of the gene containing the optimum codons would increase the expression level in *E. coli*.

Reference 2: Adair, J. R. et al. Humanization of the murine anti-human CD3 monoclonal antibody OKT3. *Hum Antibodies Hybridomas* 5, 41-7. (1994).

The humanization of the variable regions of 528 was performed by means of CDR grafting. Thus, a human antibody having FR (Frame Work) with the highest homology was screened and selected by a homology search in view of the length of each CDR and the like. An amino acid sequence was designed, in which the CDR of the selected human antibody was replaced with CDR of 528. The total gene was then synthesized by means of overlapping PCR by using the optimum codons for *E. coli* (Fig.22).

#### Example 12: Preparation of Expression Vector of Humanized Ex3

The humanized Ex3 diabody (referred to as "hExh3") was made of the two molecules of h5HhOL and hOHh5L. The expression vectors were constructed

based on the expression vectors constituting Ex3. Thus, the humanized 5H (referred to as “h5H”:SEQ ID No.29) was amplified with PCR using E·F primers comprising a restriction enzyme site, digested by NcoI·EagI, and replaced with “5H” in pRA·5HOL. Then, the humanized OL (referred to as “hOL”:SEQ ID No.28) was amplified with PCR using G·H primers comprising a restriction enzyme site, digested by EcoRV·SacII, and replaced with “OL” in pRA·5HOL to finally give pRA·h5HhOL. Similarly, the humanized OH (referred to as “hOH”:SEQ ID No.27) was amplified with PCR using I·J primers comprising a restriction enzyme site, digested by NcoI·EagI, and replaced with “OH” in pRA·OH5L. Then, the humanized 5L (referred to as “h5L”:SEQ ID No.30) was amplified with PCR using K·L primers comprising a restriction enzyme site, digested by EcoRV·SacII, and replaced with “5L” in pRA·OH5L to finally give pRA·hOHh5L. As in Ex3, a c·myc peptide tag for detection and a His·tag (His<sub>x</sub>6:histidine·hexamer) for purification were introduced successively in the vectors.

E *NcoI*·h5H back primer 5'-nnnccatggcccaggtgcaactggtcagagc·3'  
[SEQ ID No.5]

F h5H·*EagI* forward primer 5'-nnncggccgagctcacggtaaccagcgta·3'  
[SEQ ID No.6]

G *EcoRV*·hOL back primer 5'-nnngatatccagatgaccaggag·3'  
[SEQ ID No.7]

H hOL·*SacII* forward primer 5'-nnnccgcggcgccggtaatctgc·3'  
[SEQ ID No.8]

I *NcoI*·hOH back primer 5'-nnnccatggcccaggtgcaactggtg·3'  
[SEQ ID No.9]

J hOH·*EagI* forward primer 5'-nnncggccgagctaacggtcacc·3'  
[SEQ ID No.10]

K *EcoRV*·h5L back primer 5'-nnngatatcgtgatgaccaggccc·3'  
[SEQ ID No.11]

L h5L-SacII forward primer 5'-nnnccgcggcgcttaattccacttggtgccac-3'  
[SEQ ID No.12]

Example 13: Expression in E. coli, Purification and Refolding of “h5HhOL” and “hOHh5L”

E. coli. cells transformed with the expression vectors pRA-h5HhOL and pRA-hOHh5L were cultured by the same way as in Example 3. Since SDS-PAGE and Western-blotting of each fraction revealed that almost all of the “h5HhOL” and “hOHh5L” was contained in the insoluble fraction within the bacteria cell, these proteins were prepared from said insoluble fraction (Fig.24).

Purification and refolding were carried out by the same procedures as in Example 4. After being separately purified, the same quantity of “h5HhOL” and “hOHh5L” was mixed together and refolded. SDS-PAGE of the refolded hExh3 showed that they were purified with a very high degree and they had formed a homogeneous hetero-dimer (Fig.24, lanes 1 & 4: culture supernatant; lanes 2 & 5: soluble fraction within the bacteria cell; lanes 3 & 6: insoluble fraction within the bacteria cell; lane 7: after purification and refolding of hExh3; lane 8: after purification and refolding of Ex3).

Example 14: Evaluation of hExh3– Flow cytometric analysis

The binding of hExh3 was examined with Flow cytometry by the same way as in Example 5. The negative control (NC) and positive control (PC) were taken as well in the same way as in Example 5. The results showed its binding to both the T-LAK cell and TFK-1 cell as in Ex3 (Fig.25).

Example 15: Alternation of the function of hExh3 caused by introduction of mutation

Alternation of the function of hExh3 caused by introduction of mutation was examined. There has been some reports that the humanization could cause reduction and loss of the function of the antibody itself. It was therefore thought necessary to introduce a site-specific mutation into a part of the sequence that had

changed due to the humanization in the FR, which may affect the CDR structure, such as canonical structure (some fixed CDR structure) or veriner-vernier residues, so that the changed part will be modified back to that of the original mouse sequence.

The veriner-vernier residues are contained in FR and positioned in the vicinity of CDR, which are involved in the formation and adjustment of basis of CDR structure and in the binding to an antigen (Reference 3). However, the veriner-vernier residues involved in restoring of the activity are different in each antibody. It is therefore generally selected by actually preparing some mutants and evaluating their biding activities and the like, although it may be predicted to some extent by a detailed structure analysis (Reference 4, 5).

Each site-specific mutation was introduced by means of overlapping PCR. Thus, the PCR-amplified products obtained form h5H with the use of E-N primers and F-M primers were used as templates for 2<sup>nd</sup> PCR, which was done with the use of primers E-F. After the digestion with NcoI-EagI, the 2<sup>nd</sup> PCR product was replaced with h5H of pRA-h5HhOL to give pRA-h5HhOL comprising a mutant M48I of h5H (Ile instead of Met at 48; referred to as "h5H-m01"). Ten mutants were prepared by the similar manner (Table 2, Fig.26).

[Table 2]

mutant	1 <sup>st</sup> template	1 <sup>st</sup> primers	sites of mutation
h5H-m01	h5H	E-N F-M	M48I,
h5H-m02	h5H-m01	E-P F-O	M48I, A93T
h5H-m03	h5H	E-R F-Q	R66K, R71V
h5H-m04	h5H-m01	E-R F-Q	M48I, R66K, R71V
h5H-m05	h5H-m04	E-T F-S	Y27D, M48I, R66K, R71V
h5H-m06	h5H-m04	E-P F-O	M48I, R66K, R71V, A93T
h5H-m07	h5H-m03	E-V F-U	R66K, M69L, R71V, T73R
h5H-m08	h5H-m07	E-N F-M	M48I, R66K, M69L, R71V, T73R
h5H-m09	h5H-m08	E-P F-O	M48I, R66K, M69L, R17V, T73R, A93T

h5H-m10	h5H-m04	E-X F-W	M48I, R66K, R71V, I75S, S76R, A78V
M h5H-M48I(+)			5'-gcctggaatggattggtaacatttate-3' [SEQ ID No.13]
N h5H-M48I(-)			5'-gataaatgttaccaatccattccaggc -3' [SEQ ID No.14]
O h5H-A93T(+)			5'-tattactgcacgcgcagtggc-3' [SEQ ID No.15]
P h5H-A93T(-)			5'-gccactgcgcgtgcagtaata-3' [SEQ ID No.16]
Q h5H-R66KR71V(+)			5'-atttaagaacaaagtgaccatgacggttgataccagca-3' [SEQ ID No.17]
R h5H-R66KR71V(-)			5'-tgctggtatcaaccgtcatggtcactttgttcttaat-3' [SEQ ID No.18]
S h5H-Y27D(+)			5'-gcctcaggcgataccttacg-3' [SEQ ID No.19]
T h5H-Y27D(-)			5'-cgtaaaggatcgctgaggc-3' [SEQ ID No.20]
U h5H-M69LT73R(+)			5'-caaagtgaccctgacggttgatcgcagcattcga-3' [SEQ ID No.21]
V h5H-M69LT73R(-)			5'-tcgaaatgctgcgtcaaccgtcagggtcactttg-3' [SEQ ID No.22]
W h5H-I75SS76RA78V(+)			5'-gataccaggcgtcgcacggtctatatggaa-3' [SEQ ID No.23]
X h5H-I75SS76RA78V(-)			5'-ttccatatacgaccgtgcgactgctggatc-3' [SEQ ID No.24]

Reference 3: Foote, J. & Winter, G. Antibody framework residues affecting the conformation of the hypervariable loops. J. Mol. Biol. 224, 487-99. (1992).

Reference 4: Sato, K. et al. Reshaping a human antibody to inhibit the interleukin

Reference 5: Sato, K. et al. Humanization of a mouse anti-human interleukin-6 receptor antibody comparing two methods for selecting human framework regions. Mol. Immunol. 31, 371-81. (1994).

Example 16: Evaluation of hExh3 and its mutants– In vitro Cytotoxicity Test (MTS Asssay) Asssay)

The cytotoxicity in vitro of hExh3 and its mutants were evaluated by the MTS assay as in Example 7, revealing that the introduction of mutations at a few sites would significantly affect the cytotoxicity and that some of the mutants showed slightly stronger activity than that of hExh3 (Fig.27).

The cytotoxicity depending on the concentration was also observed, showing that hExh3 (left bar) and h5H-m09 (middle bar) had the same effect as that of Ex3 (right bar) (Fig.28).

#### INDUSTRIAL APPLICABILITY

It was confirmed that the diabody-type bispecific antibody according to the present invention showed an excellent cytotoxicity in vitro and in vivo. Furthermore, the addition of the diabody-type antibody to the culture system comprising the cell having phagocytosis or cytotoxic activity and the cell expressing human epidermal growth factor (EGF) receptor will significantly increase the production of cytokines by the cells having phagocytosis or cytotoxic activity. The humanized diabody-type bispecific antibody was also produced and it was confirmed that it showed the activity comparable to that derived from mouse.

It was confirmed that the diabody-type bispecific antibody according to the present invention could be stored frozen while keeping its activity for a few months, showing its excellent stability.

Accordingly, the pharmaceutical preparation comprising these diabody-type bispecific antibodies as an active ingredient has activities of eliminating, hurting, damaging and/or reducing tumor cells in vitro and in vivo, and is used as an anti-tumor agent.

WHAT IS CLAIMED:

1. A diabody-type bispecific antibody, having a first specificity to a human epidermal growth factor (EGF) receptor and a second specificity to a surface antigen expressed by a cell having phagocytosis or cytotoxic activity.
2. The diabody-type bispecific antibody according to Claim 1, wherein the human EGF receptor is a human EGF receptor 1 (HER1).
3. The diabody-type bispecific antibody according to Claim 1, wherein the cell having phagocytosis or cytotoxic activity is a cytotoxic T cell.
4. The diabody-type bispecific antibody according to Claim 1, wherein the surface antigen expressed by the cytotoxic T cell is CD3.
5. The diabody-type bispecific antibody according to Claim 1, wherein the first specificity is derived from variable regions in the heavy chain and the light chain of an anti-human EGF receptor antibody 528.
6. The diabody-type bispecific antibody according to Claim 1, wherein the second specificity is derived from variable regions in the heavy chain and the light chain of anti-CD3 antibody OKT3.
7. The diabody-type bispecific antibody according to claim 1 ~~any one of the above claims~~, which is a humanized antibody.
8. The diabody-type bispecific antibody according to Claim 7, wherein a complementary determining regions (CDRs) in the variable regions are derived from a mouse antibody, and the other parts are derived from a human antibody.

9. The diabody-type bispecific antibody according to Claim 8, having at least one CDR selected from the amino acid sequences of CDR1, CDR2 and CDR3 in the variable regions derived from a humanized anti-CD3 antibody OKT3 represented in Fig.21 and having at least one CDR selected from the amino acid sequences of CDR1, CDR2 and CDR3 in the variable regions derived from a humanized anti-human EGF receptor antibody 528 represented in Fig.22.
10. The diabody-type bispecific antibody according to Claim 9, having the amino acid sequences of CDR1, CDR2 and CDR3 in the variable regions derived from a humanized anti-CD3 antibody OKT3 represented in Fig.21 and having the amino acid sequences of CDR1, CDR2 and CDR3 in the variable regions derived from a humanized anti-human EGF receptor antibody 528 represented in Fig.22.
11. The diabody-type bispecific antibody according to Claim 10, wherein the variable regions in the heavy chain and light chain derived from the humanized anti-CD3 antibody OKT3 have an amino acid sequence represented in Fig.21, and, the variable regions in the heavy chain and light chain derived from the humanized anti-human EGF receptor antibody 528 have an amino acid sequence represented in Fig.22.
12. The diabody-type bispecific antibody according to ~~any one of claims 8—11~~ claim 8, having a site-specific mutation in a framework that can affect the CDR structure.
13. Either of the two kinds of a single-chain polypeptide constituting the diabody-type bispecific antibody according to Claim 1, or a polypeptide constituting each region contained in the single-chain polypeptide.

14. A nucleic acid encoding the single chain polypeptide or each region contained therein of Claim 13.
15. The nucleic acid according to Claim 14 having an optimum codon for a host cell in which the nucleic acid is expressed.
16. The nucleic acid according to Claim 15 having the optimum codon for E. coli.
17. A replicable cloning vector or expression vector comprising the nucleic acid according to Claim 14, 15 or 16.
18. The vector according to Claim 17, which is a plasmid vector.
19. A host cell transformed with the vector according to Claim 17.
20. The host cell according to Claim 19, which is E. coli.
21. A method for the production of the a single-chain polypeptide according to Claim 13, comprising culturing the host cell according to Claim 19 to express the nucleic acid in it, collecting and purifying the single-chain polypeptide according to Claim 13.
22. A method for the production of the diabody-type bispecific antibody according to Claim 1, comprising assembling the single-chain polypeptides produced by the method of Claim 21 to form the diabody-type bispecific antibody according to Claim 1, and separating and collecting the diabody-type antibody.
23. A pharmaceutical preparation comprising an active ingredient selected from the group consisting of the diabody-type bispecific antibody according to Claim 1, the polypeptide according to Claim 13, the nucleic acid according to

Claim 14, the vector according to Claim 17, and the host cell according to Claim 19.

24. The pharmaceutical preparation according to Claim 23 for use in eliminating, hurting, damaging and/or reducing tumor cells.
25. The pharmaceutical preparation according to Claim 23 for use in increasing the production of cytokines by the cells having phagocytosis or cytotoxic activity.
26. The pharmaceutical preparation according to Claim 23, 24 or 25 comprising as the active ingredient the humanized diabody-type bispecific antibody.
27. A method for increasing the production of cytokines by the cells having phagocytosis or cytotoxic activity, comprising adding the diabody-type bispecific antibody according to Claim 1 to a culture system containing the cells having phagocytosis or cytotoxic activity and tumor cells expressing the human EGF receptors.

SEQUENCE LISTING

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<120> Novel Diabody-type Bispecific Antibody

<130> AB02035-US

<150> JP 2003-038643

<151> 2003-02-17

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<170> PatentIn version 3.1

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Gln Val Gln Leu Gln Gln Ser Gly Ser Glu Met Ala Arg Pro Gly Ala  
1 5 10 15

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Ser Val Lys Leu Pro Cys Lys Ala Ser Gly Asp Thr Phe Thr Ser Tyr  
20 25 30

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Trp Met His Trp Val Lys Gln Arg His Gly His Gly Pro Glu Trp He  
35 40 45

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atg-eae-etc-age-agg-ctg-aca-tet-gag-gac-tet-geg-gtc-tat-tat-tgt 288  
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 35 40 45

cca-aag-etc-ctg-ate-tac-aaa-gtt-tee-gae-egc-ttt-tet-ggg-gtc-cca 192  
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1 5 10 15

tcg-gtt-aaa-gtg-aga-tgc-aaa-gee-tca-ggc-tat-acc-ttt-aeg-aga-tac 96  
Ser-Val-Lys-Val-Ser-Cys-Lys-Ala-Ser-Gly-Tyr-Thr-Phe-Thr-Ser-Tyr

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35	40	45	
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50	55	60	
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65	70	75	80
atg-gaa-ctg- <del>acc</del> -ccg- <del>cgt</del> - <del>ccg</del> -gat- <del>acc</del> - <del>ccg</del> -gtg-tat-tac-tgc Met Glu Leu Ser Arg Leu Arg Ser Asp Asp Thr Ala Val Tyr Tyr Cys		288	
85	90	95	
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Ser Arg Val Glu Ala Glu Asp Val Gly Val Tyr Tyr Cys Phe Gln Gly  
85 90 95

age eat ate eeg eea aee ttt gge eaa gge aee aaa gtg gaa att aaa 336  
Ser His Ile Pro Pro Thr Phe Gly Gln Gly Thr Lys Val Glu Ile Lys  
100 105 110

ege geg 342  
Arg Ala

## ABSTRACT

The purpose of the present invention is to provide a diabody-type bispecific antibody, which is characterized by having low immunogenicity and high infiltrating activity into tumor tissues, and by being easily mass-produced at a low cost with use of microorganisms, and by being easily altered in function by means of genetic engineering. The diabody-type bispecific antibody shows a more remarkable effect than the conventional diabody-type bispecific antibodies and chemically synthesized bispecific antibodies even in a very low concentration and in the absence of the super antigen. The present invention is related to a diabody-type bispecific antibody, having a first specificity to a human epidermal growth factor (EGF) receptor and a second specificity to a surface antigen expressed by a cell having phagocytosis or cytotoxic activity, a single-chain polypeptide constituting the antibody or each region contained therein, a nucleic acid encoding the polypeptide, a replicable cloning vector or expression vector comprising the nucleic acid, a host cell transformed with the vector, and a pharmaceutical preparation comprising thereof.

1.